Hydrogen Tutorial: Why Hydrogen, Why Now?

California Hydrogen Highway Network
Hydrogen Workshop

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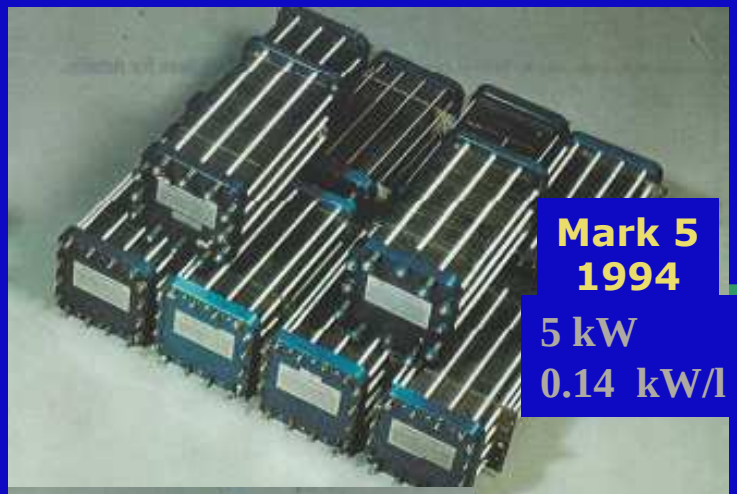
Presentation Outline

- Why Hydrogen?
- Hydrogen as a Fuel
- Methods of Production / Envt'l Impacts
- Hydrogen Applications
- Key Remaining Challenges

Why Hydrogen, Why Now?

- Hydrogen as a Transportation Fuel
  - Only hydrogen, biofuels, and battery EVs/plug-in HEVs can *simultaneously* address air pollution, GHG emissions, and energy security concerns (of known options)
  - Climate change appears to be real and serious, and we may be entering a "peak oil" regime with continued high prices and geopolitical concerns
- For Stationary Power, Hydrogen Fuel Cells Can Produce Distributed Power Locally with Low Emissions
- Great Technological Progress Over the Past 15 Years, Though Challenges Remain

Evolution of Ballard Fuel Cell Stacks



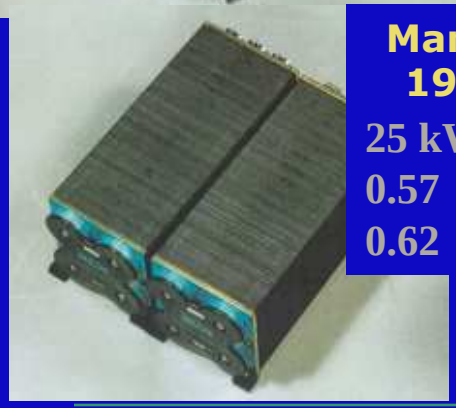
Mark 5
1994
5 kW
0.14 kW/l

Mark 9
2002
85 kW
1.1 kW/l
0.92 kW/Kg

Mark 513
1995
10 kW
0.30 kW/l

BALLARD
power to change the world

Mark 9
2000
75 kW
1.04 kW/l
0.89 kW/Kg

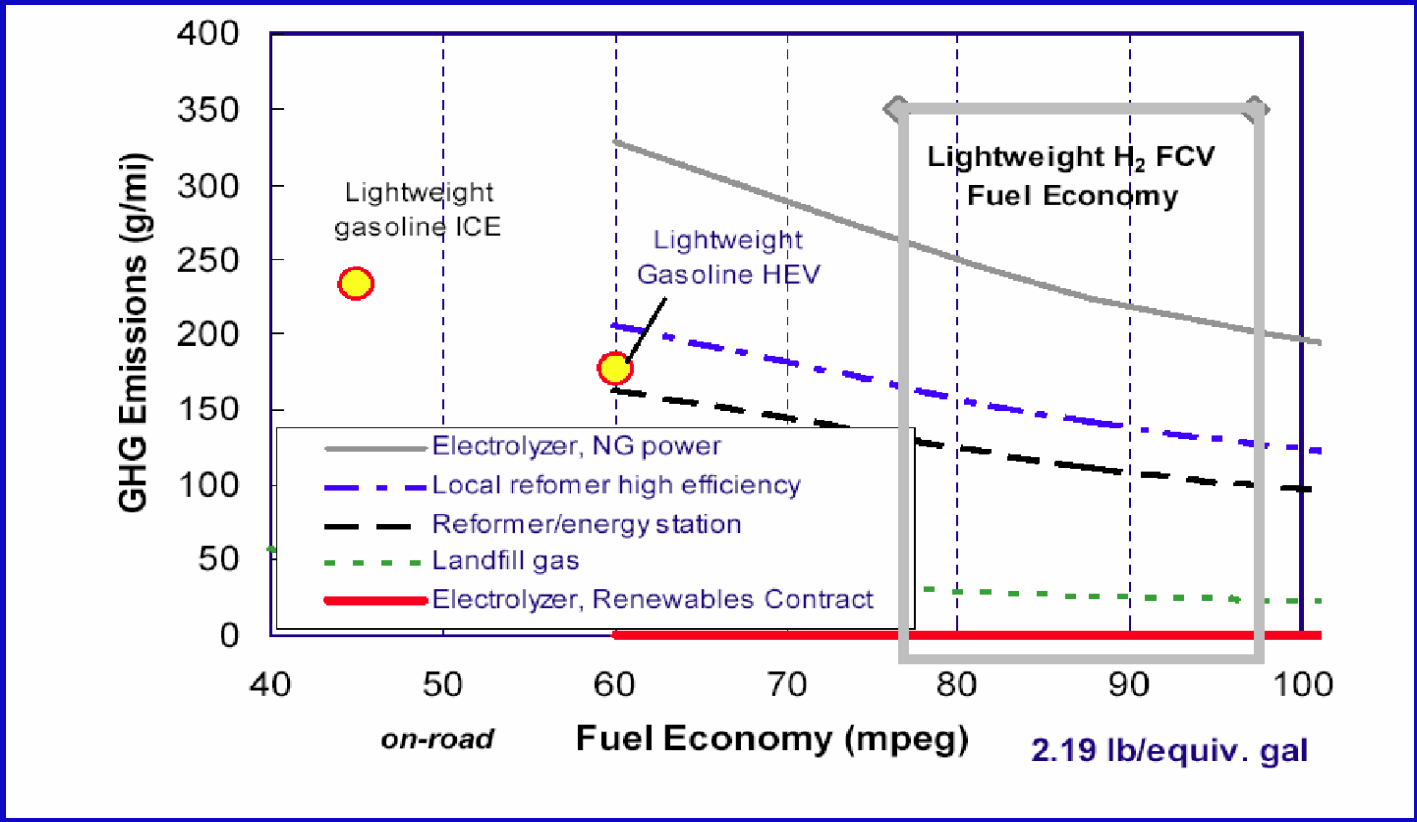


Mark 7
1996
25 kW
0.57 kW/l
0.62 kW/Kg

Mark 8
1997
50 kW
0.73 kW/l

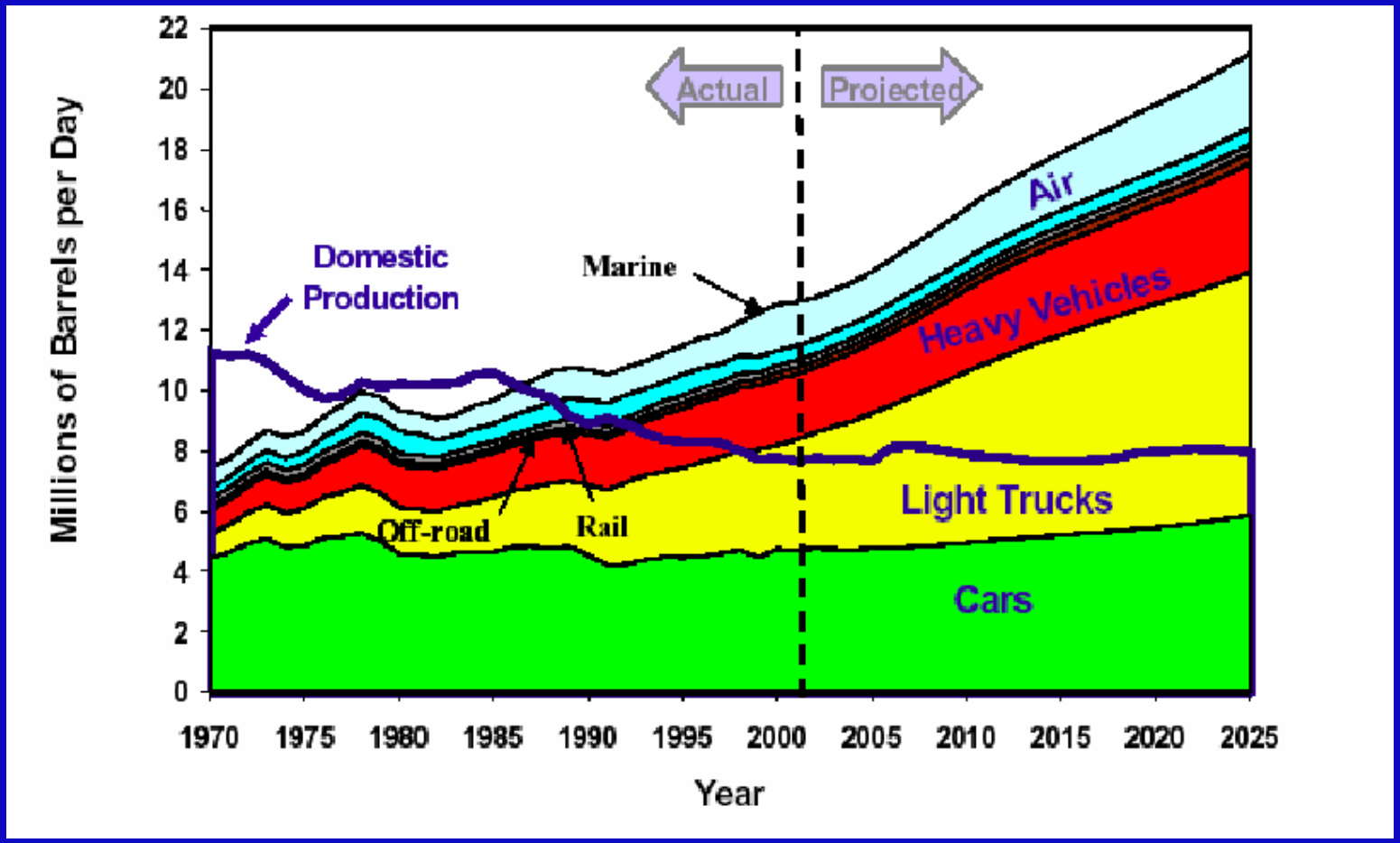
Why H2 Fuel Cells for Vehicles?

GHGs for Hydrogen FCVs vs. ICE Vehicles



Source: Bevilacqua-Knight, 2001

Why H2 Fuel Cells for Vehicles?



Source: EIA, U.S. DOE

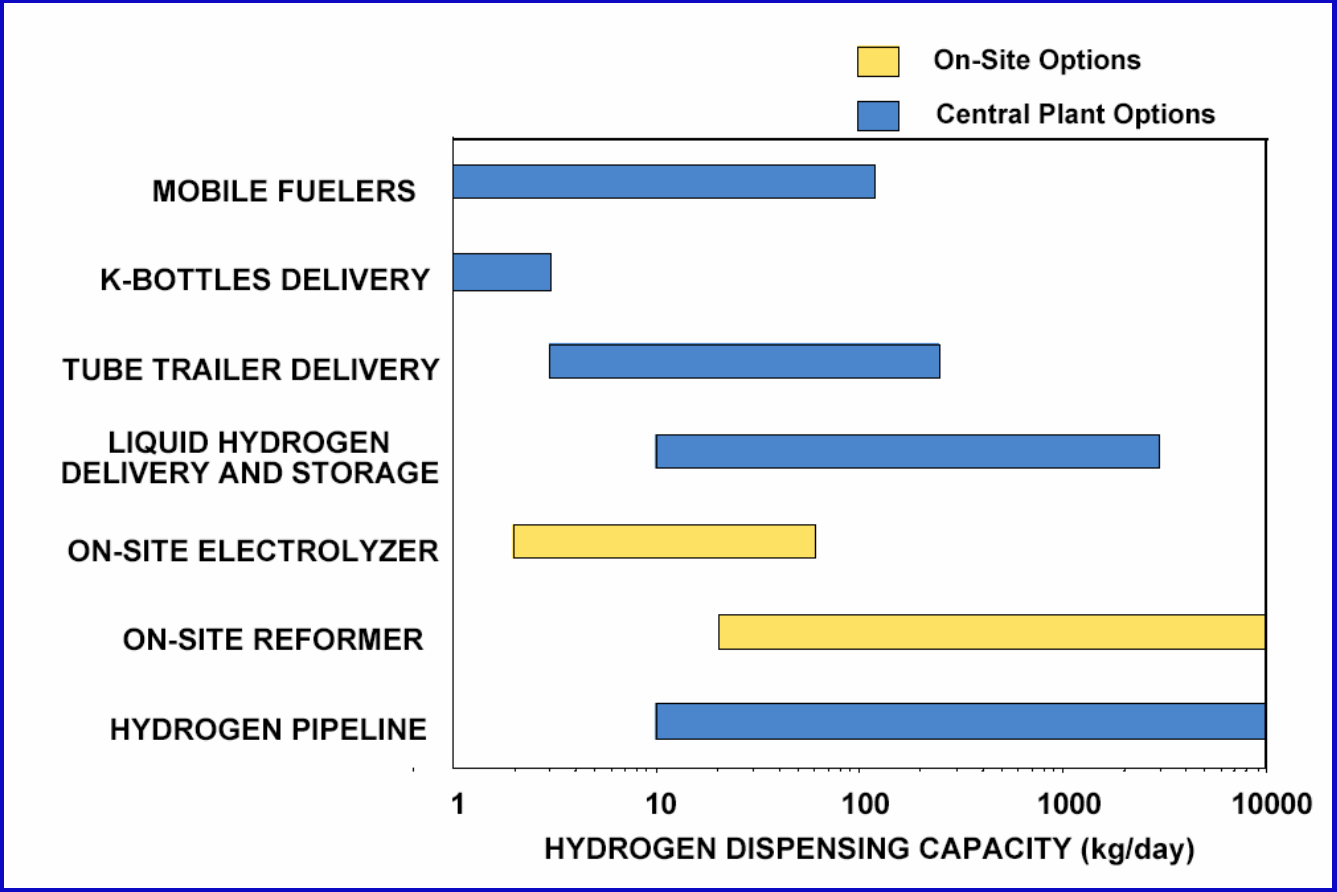
Hydrogen As a Fuel

- Hydrogen Is a Small Molecule -- Lightweight But “Bulky” Especially as a Gas
- Can Be Stored as Compressed Gas, Cryogenic Liquid, or in Solid Form in Hydrides and Other Materials
- Considered an “Energy Carrier” Rather than Primary Fuel (i.e. something we make not something we find)
- Widely Varying Environmental Impacts and Economics Depending on Production Method
- Broad Flammability Limits But Rises and Disperses Rapidly
- Dangers Are Different From Gasoline But Probably Not Worse

Hydrogen Production/Distribution

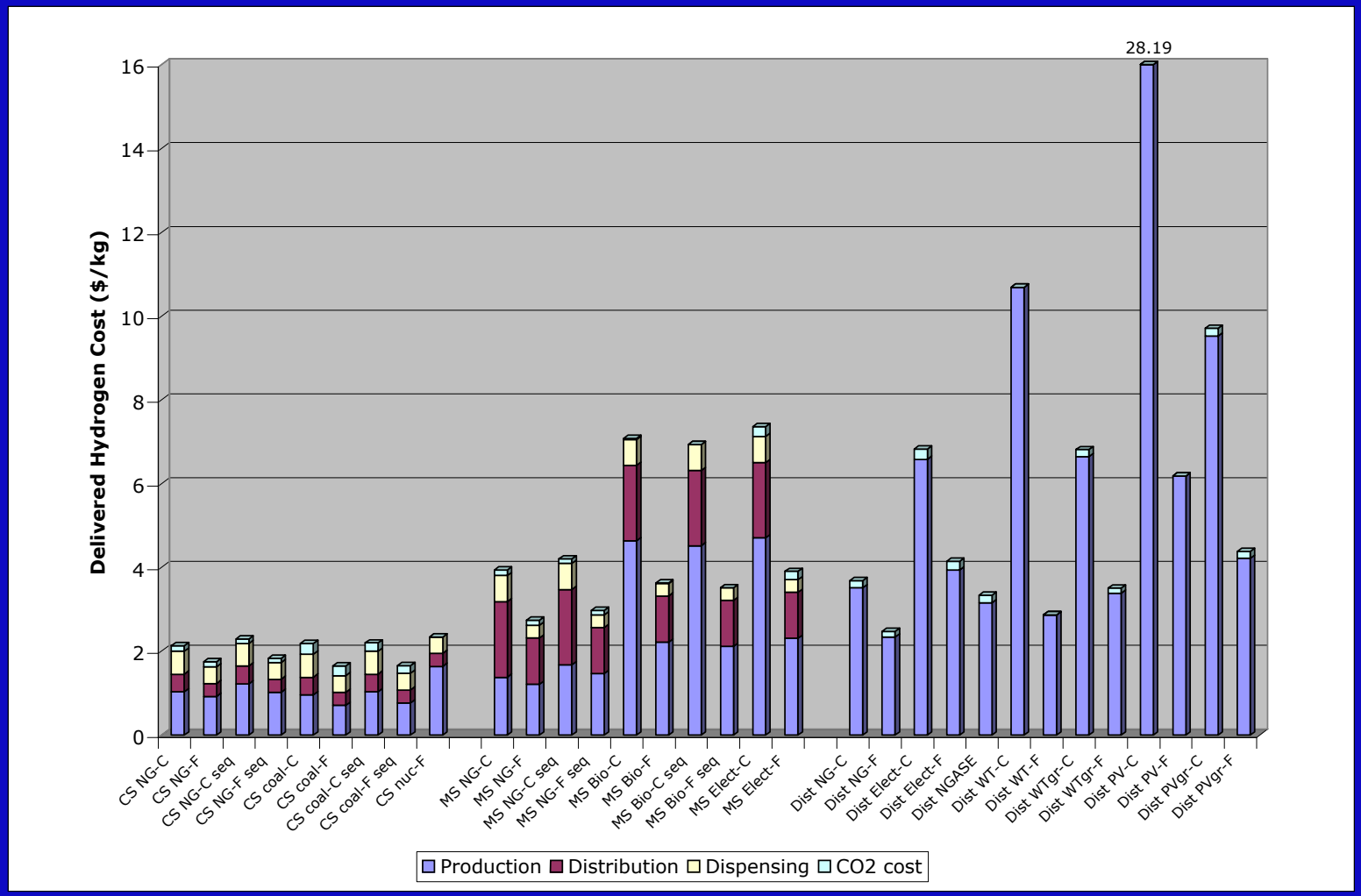
- Many Production Methods, Including Steam Reformation of Natural Gas (Methane), Electrolysis of Water Using Any Source of Electricity (including renewables), and Coal Gasification Among Others
- Various Production Scales and Transport/Delivery Options (e.g. trucks, pipelines, mobile refuelers)
- Onsite Production Has Advantage of No Need for Transportation
- “Energy Stations” for Hydrogen and Electricity Co-Production
- Again, Widely Varying Economics and Environmental Impacts

Hydrogen Production/Distribution

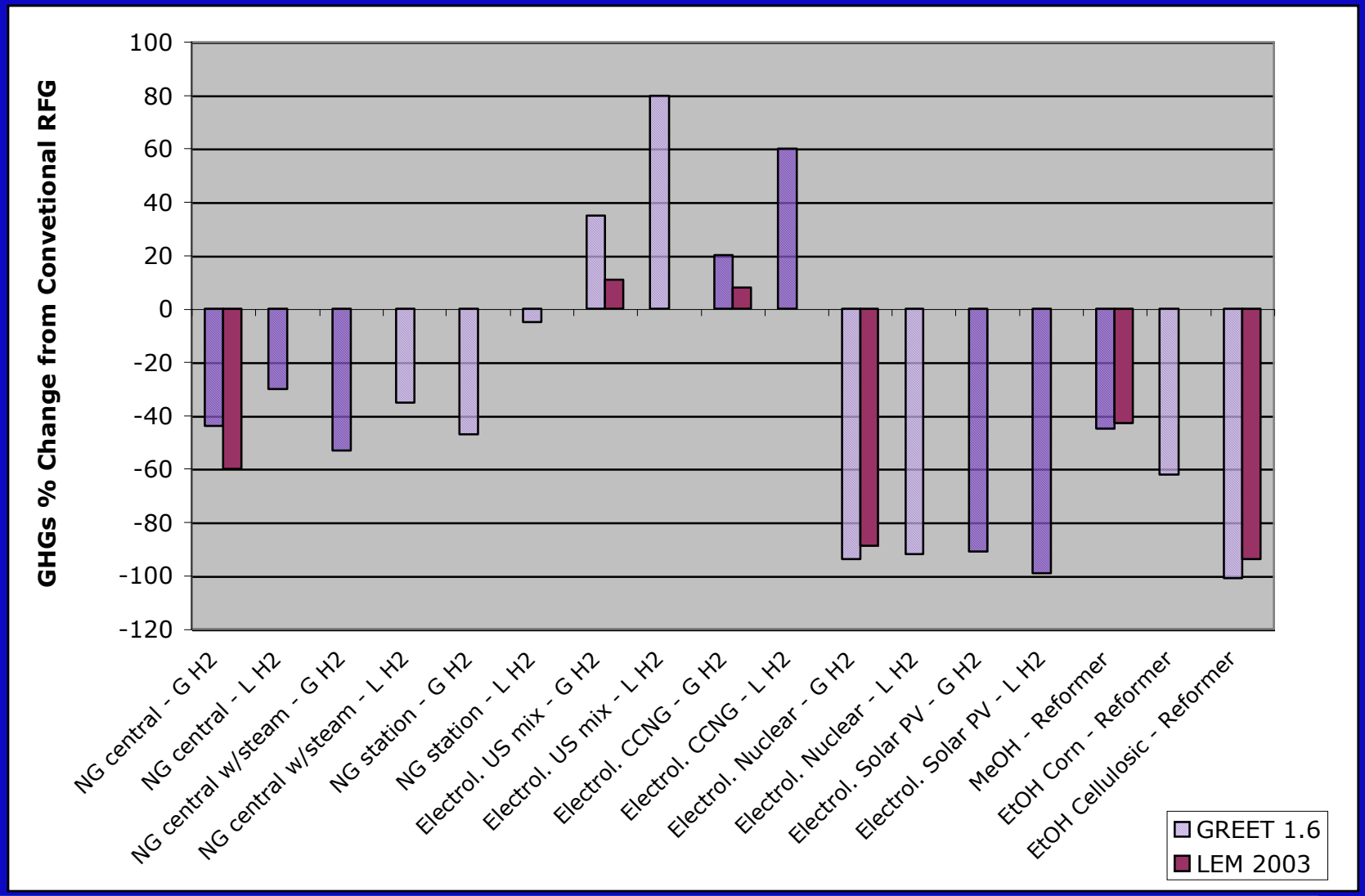


Source: Tiax

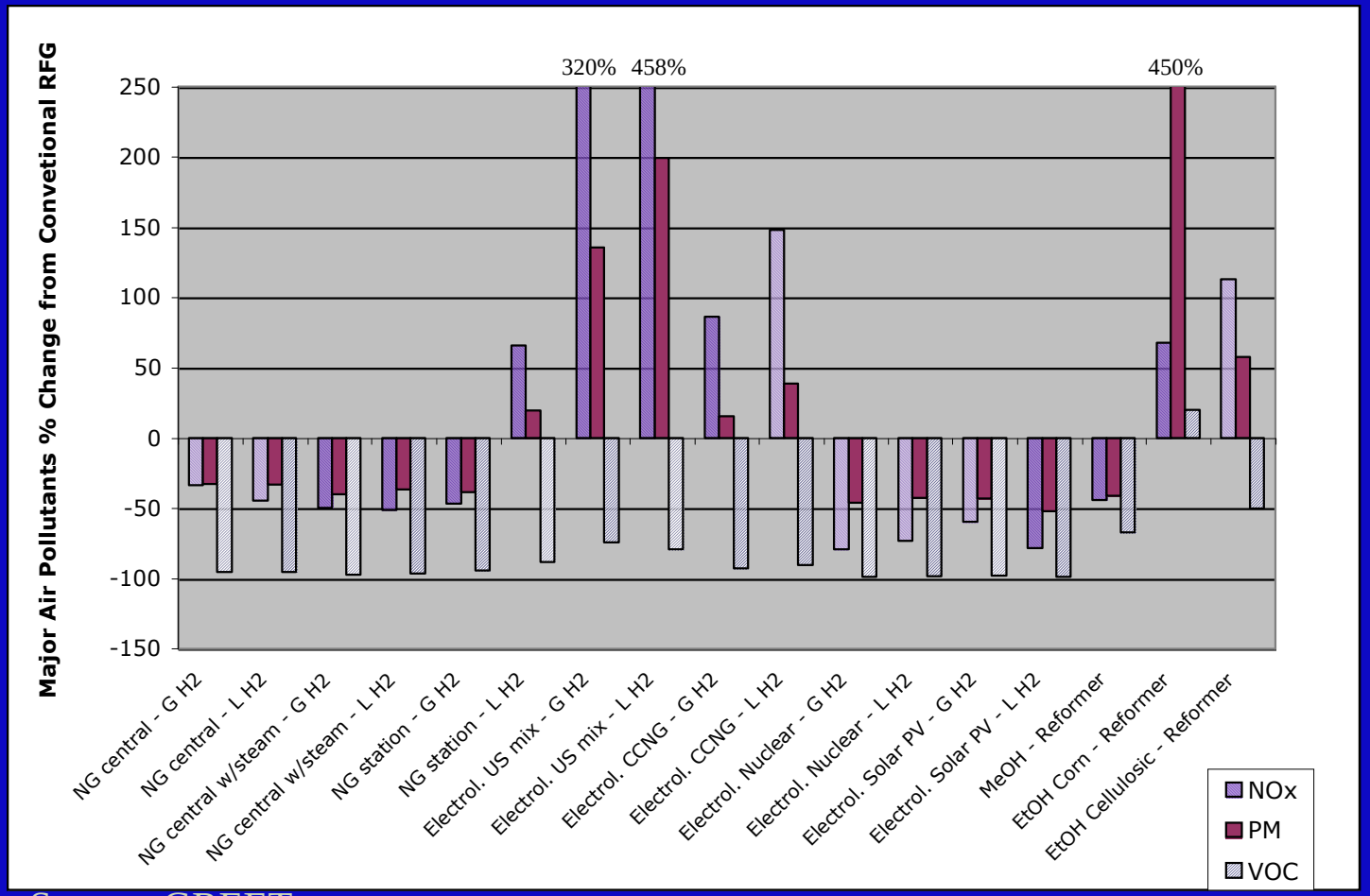
H2 Production Costs (NAS, 2004)



Greenhouse Gas Emissions

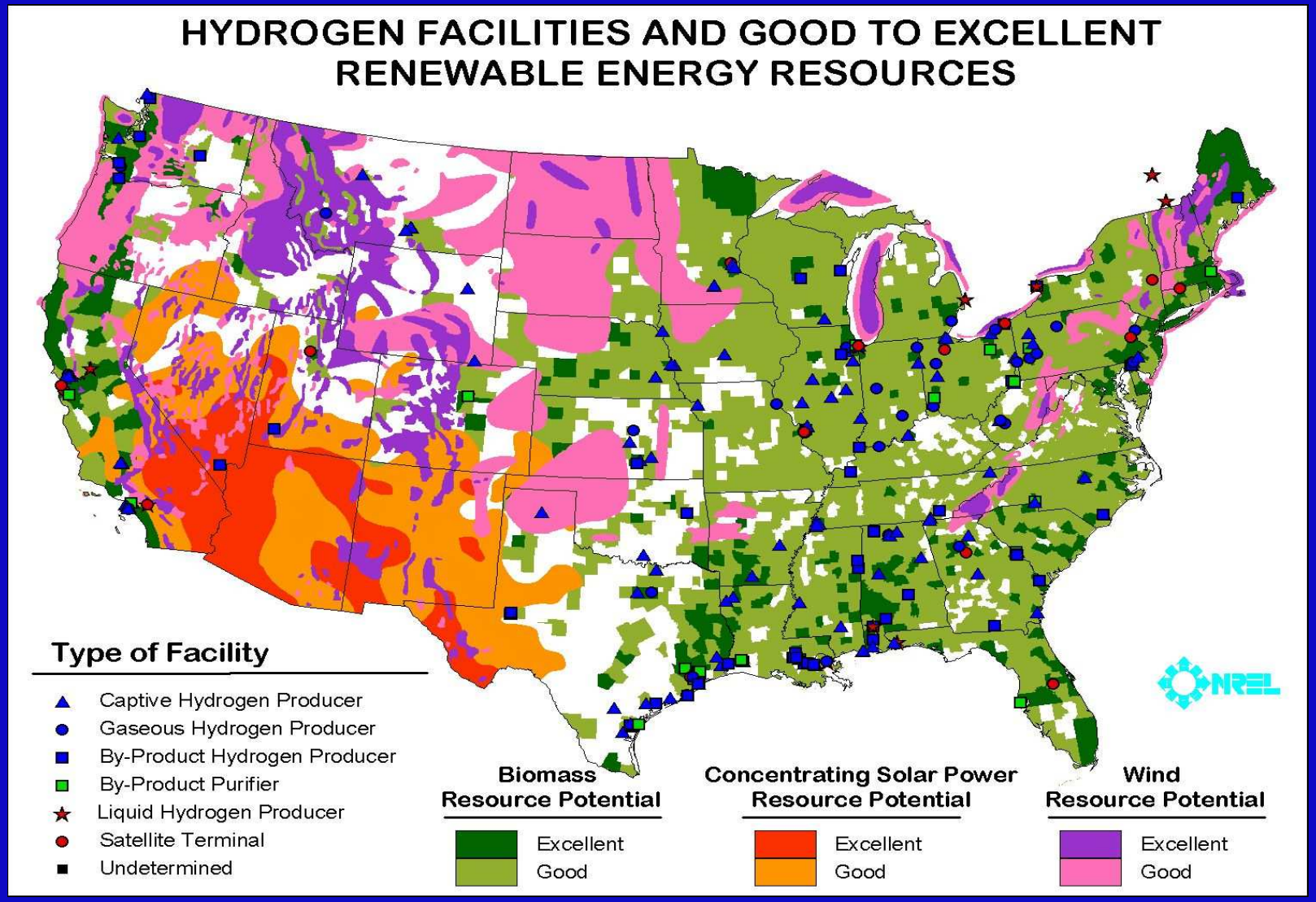


Air Pollutant Emissions



Source: GREET

Renewable Hydrogen Production



Hydrogen Applications

- Remember, Large Amounts of Hydrogen are Used Today for Oil Refining, Fertilizers, Food Production, and Other Industries
  - ~50 million tons per year globally!
- Transportation Applications
  - Low temperature fuel cells or hydrogen combustion engines
  - Buses, cars, off-road vehicles (e.g. forklifts and utility vehicles), short-haul trucks, long-haul truck APUs, etc. -- with fleet applications first
- Stationary Power Applications
  - Fuel cells or perhaps hydrogen combustion engine gen-sets
  - High temperature fuel cell systems offer best efficiencies, and excellent "combined heat and power" possibilities
- Portable Electronics Applications
  - Probably fuel cells running directly on methanol rather than hydrogen

Fuel Cell Types

	PEFC	AFC	PAFC	MCFC	ITSOFC	TSOFC
Electrolyte	Ion Exchange Membranes	Mobilized or Immobilized Potassium Hydroxide	Immobilized Liquid Phosphoric Acid	Immobilized Liquid Molten Carbonate	Ceramic	Ceramic
Operating Temperature	80°C	65°C - 220°C	205°C	650°	600-800°C	800-1000°C
Charge Carrier	H^+	OH^-	H^+	$CO3^{--}$	O^{--}	O^{--}
External Reformer for CH_4 (below)	Yes	Yes	Yes	No	No	No
Prime Cell Components	Carbon-based	Carbon-based	Graphite-based	Stainless-based	Ceramic	Ceramic
Catalyst	Platinum	Platinum	Platinum	Nickel	Perovskites	Perovskites
Product Water Management	Evaporative	Evaporative	Evaporative	Gaseous Product	Gaseous Product	Gaseous Product
Product Heat Management	Process Gas + Independent Cooling Medium	Process Gas + Electrolyte Calculation	Process Gas + Independent Cooling Medium	Internal Reforming + Process Gas	Internal Reforming + Process Gas	Internal Reforming + Process Gas

Key Remaining Challenges

- Refueling Infrastructure for Transportation
- Hydrogen Storage for Vehicles
- Fuel Cell System Integration Issues (not just stacks but optimized systems)
- Cost (vehicle FC system target of $40-50/kW!)
  - Present costs of $3,000-4,000/kW, with mass production cost estimates of ~$200/kW
- Durability (goal of ~4,000-5,000 hours for LDVs)
  - Levels of 2,000-3,000 hours have been proven, probably better than that today but again with high costs

A Little Historical Perspective…

"A new source of power…called gasoline has been produced by a Boston engineer. Instead of burning the fuel under a boiler, it is exploded inside the cylinder of an engine…"

"The dangers are obvious. Stores of gasoline in the hands of people interested primarily in profit would constitute a fire and explosive hazard of the first hank. Horseless carriages propelled by gasoline might attain speeds of 14, or even 20 miles per hour. The menace to our people of this type hurdling through our streets and along our roads and poisoning the atmosphere would call for prompt legislative action even if the military and economic implications were not so overwhelming….the cost of producing [gasoline] is far beyond the financial capacity of private industry…In addition, the development of this new power may displace the use of horses, which would wreck our agriculture."

Congressional Record, 1875

For More Information

- Lipman, T. (2004), *What Will Power the Hydrogen Economy? Present and Future Sources of Hydrogen Energy*, Institute of Transportation Studies, University of California - Davis, UCD-ITS-RR-04-10, July (http://www.its.ucdavis.edu/publications)
- Lipman, T., D. Kammen, J. Ogden, D. Sperling, A. Eggert, P. Lehman, S. Shaheen, and D. Shearer (2004), *An Integrated Hydrogen Vision for California*, Prepared for the Kirsch Foundation, Renewable and Appropriate Energy Laboratory, UC - Berkeley (http://socrates.berkeley.edu/~rael)
- Sperling, D. and J. Ogden (2004), "The Hope for Hydrogen," *Issues in Science and Technology*, Spring 2004 (http://www.its.ucdavis.edu/publications)
- Romm, J. (2004), *The Hype About Hydrogen: Fact and Fiction in the Race to Save the Climate*, Island Press (for a skeptical view)
- Sperling, D. and J. Cannon (2004), *The Hydrogen Energy Transition*, Elsevier Books